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MILTON WHITNEY, Chief.

THE ELECTRICAL BRIDGE FOR THE DETERMINATION OF SOLUBLE SALTS IN SOILS.

BY

R. O. E. DAVIS AND H. BRYAN.

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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Soils,
Washington, D. C., August 9, 1910.

Sir: I have the honor to transmit herewith the manuscript of an article on The Electrical Bridge for the Determination of Soluble Salts in Soils, by R. O. E. Davis and H. Bryan, of this Bureau, and to recommend that it be published as Bulletin No. 61 of the Bureau of Soils.

Very respectfully,

Milton Whitney,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

PREFACE.

One of the most valuable of the earlier achievements of the Division (now Bureau) of Soils was the adoption of the principle of the slide wire bridge to measurements in the soil, and the designing and constructing of suitable instruments for these purposes. The earlier instruments have been described in bulletins [a], and the results obtained with them are to be found scattered through the various publications of the Bureau. Since the instruments were first put into practical use the experience gained with them has led to modifications from time to time, improving them for the particular purposes and the exigencies of the Bureau's investigations.

In the earlier work of the Bureau one and the same form of instrument, differing only in the scale readings, was used for measuring the temperature, the water content, and the content of soluble salts of the soil. The great recent development in metallurgy, and the extension of pyrometry consequent thereon, has led to improvements and modifications in the slide wire method, so that there are now available on the market instruments admirably adapted to measuring soil temperatures.

For measuring the content of soil moisture or as a soil hygrometer no form of the slide wire instrument has proven entirely satisfactory. This is the more unfortunate as no other satisfactory device has been suggested, and soil hygrometry is practically one of the most important, and theoretically one of the most attractive, branches of soil investigation. Mechanical difficulties with the electrodes, translocation of soil solutes, absorption effects, etc., require so frequent a standardization of the electrical hygrometer that it possesses no practical advantages over the auger and ordinary drying oven, is less accurate, and is therefore not to be recommended in its present form.

As disappointing as has been the soil hygrometer, far greater has been the success of the slide wire bridge in giving quick and approximate determinations of the soluble salt content of soils. Its use in studying soils and waters in humid areas has been very large, while

[a] Bul. No. 6, Division of Soils, U. S. Dept. of Agr., 1899; Bul. No. 7, Division of Soils, U. S. Dept. of Agr., 1899; Bul. No. 8, Division of Soils, U. S. Dept. of Agr., 1897; Bul. No. 12, Division of Soils, U. S. Dept. of Agr., 1897; Bul. No. 15, Division of Soils, U. S. Dept. of Agr., 1899; Circular No. 6, Division of Soils, U. S. Dept. of Agr., 1900.

in arid areas it has been indispensable. In its present form it is far more convenient to handle than were the earlier instruments, it is capable of greater accuracy and a wider range of usefulness, and is less likely to get out of repair. It is essentially different in principle from the electrical soil thermometers now on the market, and is designed and adapted to the special purpose of determining the content of soluble salts present in the soil or water under examination.

The demand for this instrument from soil investigators, railroad chemists, and others is now quite large and evidently increasing. As yet no suitable form of the instrument is on the market, and it is obviously impracticable for the Bureau to furnish them for other than its own investigations. Therefore, Doctor Davis and Mr. Bryan have prepared this bulletin describing the latest form of the instrument, and its use, together with full working drawings. It can be easily constructed from readily available materials by any instrument maker or laboratory worker who is familiar with the use of tools.

Frank K. Cameron,
In Charge Physical and Chemical Investigations.

CONTENTS.

	Page.
Introduction	9
Development of the instrument	9
General utility	9
Theory and design of the bridge	10
Experimental work on the bridge	13
Change of resistance due to soil texture	13
Behavior of carbonates	15
Effect of organic matter	16
Time required for equilibrium	18
Measurement of concentrated solutions	19
Conclusions	20
The temperature correction	21
Field directions for the use of the bridge	25
Standardizing an area	26
Use on soil solutions	27
Care of the bridge	30
Testing the bridge	30
Location of faults	30
Detailed description of the bridge	31
Bridge box	31
Bottom compartment	32
Induction coil	32
Battery switch	32
Battery	32
Cup post	33
Middle compartment	33
Bridge wire disk	33
Bridge wire	33
Balancing mechanism	33
Rotary switches	34
The coils	35
The scale	35
Contact clips	35
Indicator	35
Telephone receiver	35
Cup	36
Brass clip	36
Top	36

ILLUSTRATIONS.

PLATES.

		Page.
PLATE I.	Bridge box with top raised, showing cup in position ready for use...	16
II.	Bridge box open, showing interior	16
III.	Sheet No. 1. Drawings of bridge assembled	In pocket
IV.	Sheet No. 2. Details of bridge	In pocket
V.	Sheet No. 3. Details of bridge	In pocket

TEXT FIGURES.

FIG. 1.	Diagram of Wheatstone's bridge	10
2.	Diagram of Wheatstone's bridge for use with solutions	11
3.	Diagram of modified bridge for field use	11
4.	Diagram of interior connections for field bridge	12
5.	Curves for Portsmouth sand with sodium carbonate, sulphate, and chloride	17
6.	Curves for ignited Portsmouth sand with sodium carbonate, sulphate, and chloride	18
7.	Curves for sodium carbonate with Portsmouth sand and ignited Portsmouth sand	19

THE ELECTRICAL BRIDGE FOR THE DETERMINATION OF SOLUBLE SALTS IN SOILS.

INTRODUCTION.

DEVELOPMENT OF THE INSTRUMENT.

The use of electric methods for determining the soluble salt content of a soil depends on the fact that the electric current is conducted by the salt in solution and that the conductance of the solution or, conversely, its resistance to the passage of the current, is determined largely by its concentration. The magnitude of current that will pass is increased by an increase of salt in solution; or the resistance to the passage of the current decreases with the increase of salt. The conductance is also affected by the quantity of water present and by the temperature. Whitney and Means [a] have shown that the conductance of soils increases with the increase in moisture content and is almost proportional thereto. In the method described in this bulletin for determining the amount of salt in solution, the water content for any one soil studied is practically constant.

In 1897 [b] this Bureau published a description of an electrical instrument to be used for the determination of soluble salts in soils. This instrument was later modified and other publications [c] upon the method were issued. It is now thought advisable to embody the results of further experience in a bulletin which discusses the practical use of the method.

GENERAL UTILITY.

The instrument is of general utility in measuring the resistances of solutions and of soils. It is designed primarily for use as a field instrument, and finds its greatest use in determinations of "alkali," or harmful excess of soluble salts, frequently present in the soils of arid and semiarid areas. In survey work it gives a convenient method for determining in the field the percentage of alkali in a soil, so that the mapping may be carried on concurrently. It is also useful in determining the salt content of irrigation and seepage waters. In

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[a] Bul. No. 8, Division of Soils, U. S. Dept. of Agr., 1897, p. 16.

[b] Bul. No. 8, Division of Soils, U. S. Dept. of Agr., 1897.

[c] Bul. No. 15, Division of Soils, U. S. Dept. of Agr., 1899; Circular No. 6, Division of Soils, U. S. Dept. of Agr., 1900.

the laboratory it is used for standardization work and for determining the amount of soluble salts in soil extracts.

In a new design of the bridge an extra 100-ohm coil has been added, so that it may be thrown in series with the cup. The description of the new design is given in this bulletin.

THEORY AND DESIGN OF THE BRIDGE.

The instrument, by means of which resistances are measured, is a modified form of Wheatstone's bridge. The ordinary Wheatstone bridge consists of an arrangement shown in figure 1. Current from a battery, *B*, is led to a point, *a*, where it divides into two branches, *abc* and *adc*, uniting at *c* to return to the other pole of the battery. Two points, *b* and *d*, of the branched conductors are connected through a galvanometer, *G*. No current will flow through *G* if the resistances *ab*, *bc*, *ad*, and *dc* are such that $ab \times dc = bc \times ad$. Hence, if three of the values are known, the fourth may be calculated. Should a solution in a cell be introduced into one of the resistances, say *bc*, the arrangement must be somewhat modified. A direct current of electricity passing through a solution between metal electrodes causes the separation of gases at the electrodes and an electric potential in the opposite direction to that of the current is set up. This phenomenon is known as polarization. It, of course, interferes with the correctness of the measurement. To prevent polarization an alternating current may be used.

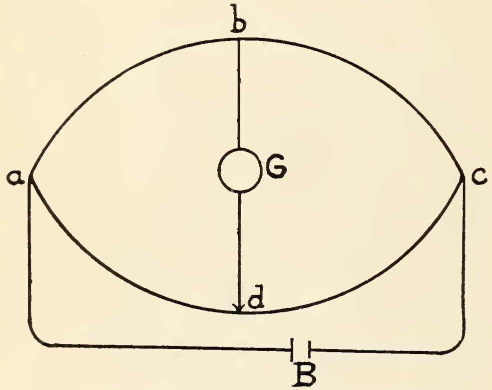


FIG. 1.—Diagram of Wheatstone's bridge.

When an alternating current is needed, the Wheatstone bridge is modified as shown in figure 2. In place of the galvanometer, a telephone receiver is used. A slide-wire bridge is employed; that is, for *adc*, a wire of uniform resistance along its length is stretched upon a millimeter scale. In the branch *ab*, a known resistance, *R*, is introduced and in *bc* the cell, *K*, of unknown resistance which is to be determined. By moving the sliding contact *d* to such a position that the sound in the telephone receiver disappears or is reduced to a minimum, the resistances are then such that the length $ad \times K =$ length $dc \times R$. From this *K*, the only unknown quantity is easily calculated. The alternating current is furnished by an induction coil with current interrupter, *I*. *P* is the primary and *S* the secondary coil.

The arrangement of the modified form is shown in figure 3. *B* is the battery, *P* the primary of the induction coil, *S* the secondary, *ab* contains the known resistance, *R*; *bc* contains the cup, *K*, the resistance of which is to be measured; and *adc* is the graduated bridge wire stretched on a circular disk. The telephone connects *b* with a sliding contact, *d*, on the bridge wire. The tone minimum is obtained by rotating at *O* a shaft connected with the movable contact, *d*. When a balance is obtained in this way, the resistance of the material in the cup is readily determined. The scale for the bridge wire is not divided into equal *lengths*, as in the ordinary Wheatstone bridge, but is graduated by the use, in place of the cup, *K*, of known resistances from 0.4 ohm to 10 ohms; and, in the arm *ab*, of a 10-ohm coil.

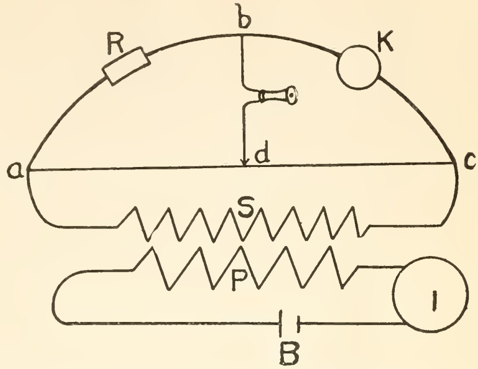


FIG. 2.—Diagram of Wheatstone's bridge for use with solutions.

In any measurement with the cup, the product $R \times cd$, or the known resistance by the number on the scale, gives the resistance of the cup, *K*.

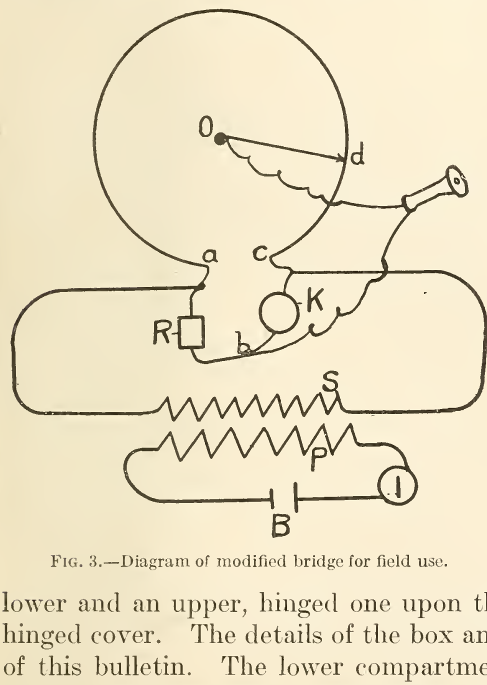


FIG. 3.—Diagram of modified bridge for field use.

Figure 4 shows in detail the connections of the field instrument. This instrument consists of a slide wire, a small induction coil, a battery, resistances, a telephone receiver, and a cup to contain the soil, all inclosed in a small wooden box, so that it may be conveniently carried in the field. The box is made in two compartments, a lower and an upper, hinged one upon the other and supplied with a hinged cover. The details of the box and bridge are given at the end of this bulletin. The lower compartment contains the battery, *A*,[a]

[a] Letters refer to drawings in pocket at the end of this bulletin.

induction coil, *C*, and switch *B*, all permanently attached to the box, and a place *Q*, for the cup when not in use. On the underside of its cover are the disk *E*, carrying the bridge wire, and the resistances, *H*. On top of this cover, and in what comprises the upper compartment, are the scale, *P*, and plunger, *O*, carrying a pointer for reading resistances; the holder, *Q*, for the cup; the switch, *F*, for the comparison coil; switch, *G*, for the cup-coil; and the telephone receiver, *M*. The top simply serves to protect the instrument when not in use. The top is supplied with a handle for convenience in carrying when the instrument is closed. Plates I and II are two views of the bridge, one

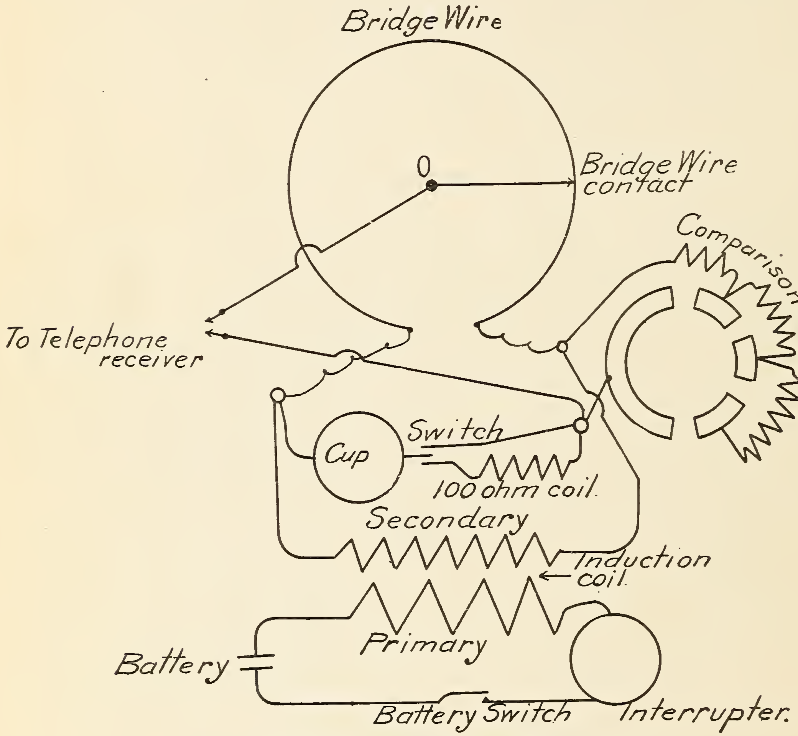


FIG. 4.—Diagram of interior connections for field bridge.

with the cup in place ready for measuring the resistance of a sample and the other with the bridge open, showing interior construction.

In operating the bridge, the cup is filled with the soil saturated with water and placed in the clips provided for it. The resistance of the cup contents is then read, and from the resistance the amount of soluble salt present determined by reference to the tables given on subsequent pages. In measuring resistances of soils and soil solutions, errors may result from several causes. The resistance of a soil will be influenced by the texture, increasing as the fineness in texture increases. The chemical composition of the soluble salt in the soil

will also influence the resistance, since different salts have different values for their conductance. Still another cause of error is the presence of organic matter in the soil. Resistances change with a change of temperature, therefore all resistances, to be comparable, should be made at, or reduced to, the same temperature. Finally, with the solutions of high conductance, it is difficult to locate the minimum on the scale.

In order to study these causes of difference in the measurement of resistances it was necessary to make a number of experiments with the bridge.

EXPERIMENTAL WORK ON THE BRIDGE.

CHANGE OF RESISTANCE DUE TO SOIL TEXTURE.

Using the bridge as described in detail below, curves were made for quartz sand, Norfolk loam, Norfolk clay loam, Sharkey clay, and carborundum, using sodium chloride, sodium sulphate, and sodium carbonate separately with each. In each case the amount of water necessary to saturate the dry substance was determined. Then weighed amounts of salt were dissolved in just enough water to saturate a given weight of soil. The solution and soil were then thoroughly mixed with a spatula. The soil paste was put into the cup and the resistance of the cup contents determined as described elsewhere.

The results are given in Table I. The soils, excepting the clay loam, used were not representative types, but they serve to bring out clearly certain relations. Thus the ratios of solution resistance to the soil resistance at the various percentages are given. It is noticed that in the cases of sodium chloride and sodium sulphate the ratios correspond closely at any given percentage; but with sodium carbonate there is no correspondence, except in the case of sand.

TABLE I.—*Resistances at 60° F. and ratios of solution resistances to soil resistances with the same salt content.*

Per cent of salt content.	Resistance at 60° F.						Ratio of resistance of solution to resistance of—				
	Solution.	Sand.	Loam.	Clay loam.	Clay.	Carborundum.	Sand.	Loam.	Clay loam.	Clay.	Carborundum.
NaCl:	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*					
3.00....	11	20	19	17	20	....	0.55	0.58	0.65	0.55	....
1.00....	22	43	34	32	34	24	.51	.65	.69	.65	0.92
.60....	34	64	55	50	48	38	.53	.62	.68	.71	.90
.40....	46	80	75	72	60	48	.57	.62	.64	.77	.91
.20....	89	118	131	129	82	85	.75	.68	.69	1.10	1.05
Na_2SO_4:											
3.00....	13	25	23	23	26	....	.52	.57	.57	.50	....
1.00....	34	63	50	52	50	36	.54	.68	.65	.68	.94
.60....	49	94	73	78	66	52	.52	.67	.63	.79	.94
.40....	67	119	96	112	78	71	.56	.70	.60	.81	.94
.20....	122	156	164	202	100	122	.77	.74	.61	1.22	1.00
Na_2CO_3:											
3.00....	12	22	25	25	40	....	.55	.48	.48	.30	....
1.00....	24	46	53	69	83	30	.52	.45	.35	.29	.80
.60....	35	66	95	126	100	44	.53	.37	.28	.35	.80
.40....	51	86	140	204	110	65	.59	.33	.25	.46	.78
.20....	94	150	262	383	130	120	.60	.36	.25	.72	.78

Since there is such a difference in the carbonate measurements from those with sulphate and chloride, two sets of measurements were made on what were considered samples representative of four classes of soil. One set of measurements was for resistances with equal parts chloride and sulphate and the others with carbonate. The soils used were composite samples made up from the following:

Sand; Norfolk No. 10774; Miami Nos. 11440, 11516.

Loam; Sassafras No. 17003; Miami Nos. 11500, 11976; Hagerstown Nos. 4952, 10168.

Clay; Cecil Nos. 7692, 9787; Hagerstown Nos. 9817, 20063, 17070.

Clay loam; Miami Nos. 11977, 13216, 11975, 19976.

The results are given in Table II. In the last four columns of this table are given the ratios of soil resistances to solution resistances at given percentages. These, it will be noticed, are very regular for the chloride and the sulphate mixture. From the measurements, curves for the different soils have been plotted and the percentage of salts for different resistances determined from the curves. These are given in Table III. For general field work the averages of Table II may be used when carbonates are absent, as the values for the different classes of soil differ but slightly.

TABLE II.—*Resistances of soil types containing sulphate and chloride.*

Salt content (sulphates and chlorides).	Resistance at 60° F.						Ratio of soil resistance to solution resistance.			
	Solution.	Sand.	Loam.	Clay loam.	Clay.	Average.	Sand.	Loam.	Clay loam.	Clay.
Per cent.	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*				
3.00	12	17.8	17.9	19.0	21.0	18.9	1.48	1.49	1.58	1.75
1.00	25	36.4	37.9	41.5	44.5	40.1	1.46	1.53	1.66	1.76
.60	39	55.4	57.6	62.0	68.4	60.9	1.42	1.48	1.59	1.76
.40	58	83.6	68.8	92.5	98.5	90.4	1.44	1.49	1.60	1.70
.20	106	153.0	158.9	164.5	174.1	162.6	1.44	1.50	1.57	1.64
Average ratio							1.45	1.50	1.60	1.72

TABLE III.—*Percentage of mixed salt in soil types with given resistances.*

Resistance at 60° F.	Sand.	Loam.	Clay loam.	Clay.	Resistance at 60° F.	Sand.	Loam.	Clay loam.	Clay.
Ohms.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Ohms.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
18	3.00	3.00	....	....	95	0.35	0.37	0.39	0.42
19	2.40	2.64	3.00	....	100	.33	.35	.37	.39
20	2.20	2.42	2.80	3.00	105	.31	.33	.35	.37
25	1.50	1.70	1.94	2.20	110	.30	.32	.33	.35
30	1.24	1.34	1.46	1.58	115	.28	.29	.31	.33
35	1.04	1.14	1.22	1.32	120	.27	.28	.29	.32
40	.86	.94	1.04	1.14	125	.25	.26	.28	.30
45	.75	.78	.88	.98	130	.24	.25	.26	.28
50	.67	.71	.77	.86	135	.23	.24	.25	.27
55	.60	.64	.69	.77	140	.22	.23	.24	26
60	.55	.58	.63	.70	145	.21	.22	.23	.25
65	.51	.54	.57	.63	150	.21	.21	.22	.24
70	.48	.50	.53	.59	155	.20	.21	.21	.23
75	.45	.47	..50	.55	160	.20	.20	.21	.22
80	.42	.44	.47	.51	165	.19	.20	.20	.21
85	.39	.42	.44	.48	170	.19	.19	.20	.20
90	.37	.39	.41	.45					

BEHAVIOR OF CARBONATES.

From Table I it is seen that the presence of carbonates tends to lower the ratio of solution resistance to soil resistance. Even in carborundum the effect of carbonate in lowering the ratio is similar to that on soils of fine texture. To determine whether this change in the ratio with carbonate is proportional to the amount of carbonate, a series of measurements were made on loam with a varying salt content of equal parts of sulphate and carbonate. The results are seen in Table IV. Here three sets of ratios are given: (1) The ratios of resistances of a solution of mixed sodium sulphate and carbonate to the resistances of loam with the mixed salt; (2) the ratios of the mean resistances of sulphate and carbonate solutions to those of loam with mixed salt; and (3) the ratio of the mean resistances of the solutions to the mean resistances of loam with each salt. These three ratios correspond very closely, or the ratio between mixed solution and loam is the same as between the mean of the solutions and loam; hence the change in the ratio due to the carbonate is proportional to the amount of carbonate present.

The measurements in Table V show the effect of carbonate upon the ratio of soil resistance to solution resistance. Not only does the ratio vary with texture, but also with change in the percentage of salt present. Table VI gives the percentages of carbonate in soil types with given resistances.

TABLE IV.—*Relation of resistances of soils containing mixed salt to resistances of soils containing each salt separately.*

Salt content.	Resistance at 60° F.				Ratio of the resistance of solution to resistance of soil.		
	Solution of mixed Na_2SO_4 Na_2CO_3.	Mean of solutions of Na_2SO_4 Na_2CO_3.	Loam and mixed salt.	Mean of loam with each salt.	Mixed salt to loam.	Mean of solutions to loam and mixed salt.	Mean of solutions to mean of loam.
Per cent.	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*			
3.00	12	13	24	24	0.50	0.54	0.54
1.00	27	29	51	52	.53	.57	.56
.60	40	42	82	82	.49	.51	.51
.40	58	59	117	118	.50	.50	.50
.20	107	108	203	213	.52	.53	.51

TABLE V.—*Resistances of soil types containing carbonate.*

Salt content.	Resistance at 60° F.					Ratio of soil resistance to solution resistance.			
	Solution.	Sand.	Loam.	Clay loam.	Clay.	Sand.	Loam.	Clay loam.	Clay.
Per cent.	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*	*Ohms.*				
3.00	12	23.6	24.6	24.6	30.0	2.00	2.08	2.08	2.50
1.00	24	54.7	68.5	69.4	96.1	2.19	2.86	2.86	4.00
.60	35	82.6	114.8	126.2	152.5	2.36	3.29	3.57	4.35
.40	51	131.6	168.1	201.9	216.2	2.58	3.30	4.00	4.25
.20	94	270.6	312.3	376.2	377.4	2.78	3.32	4.00	4.00

TABLE VI.—*Percentage of carbonate in soil types with given resistances.*

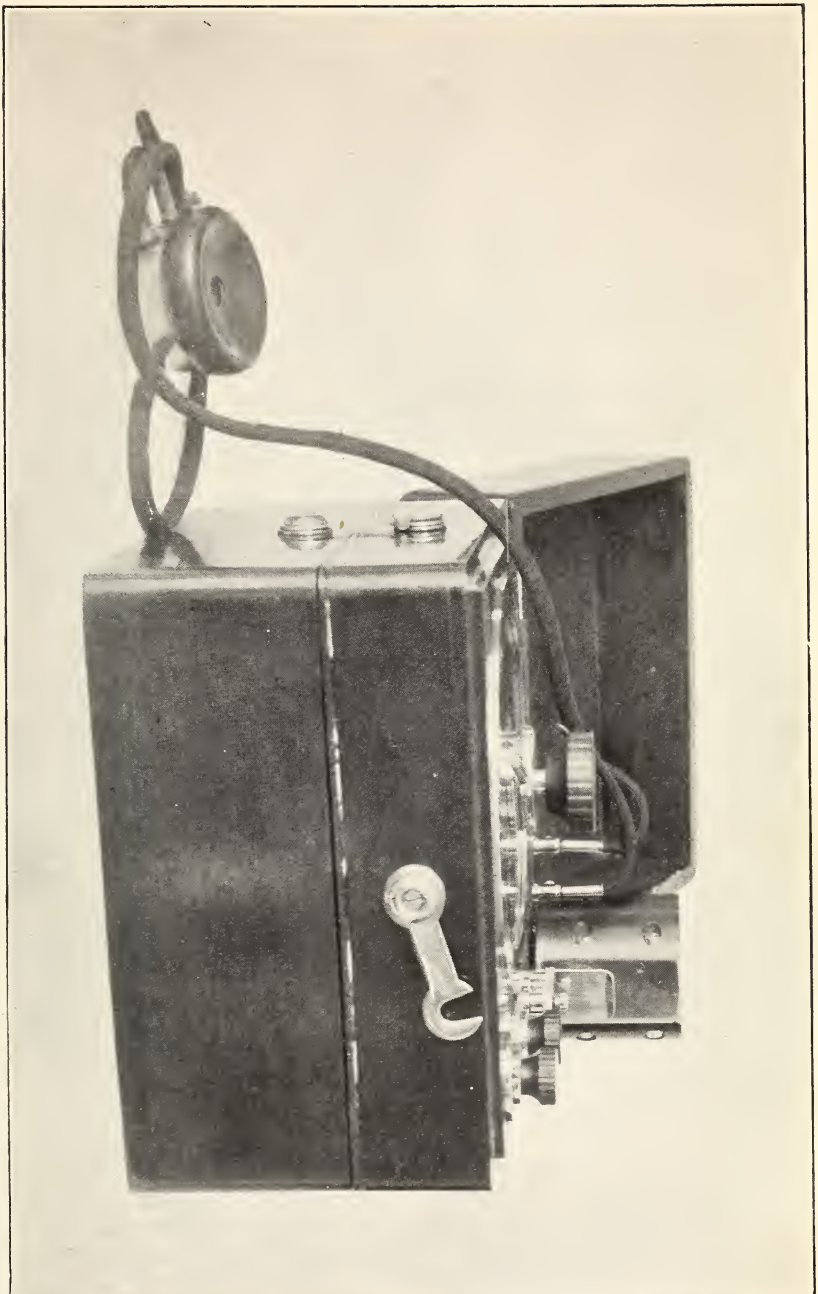
Resistance at 60° F.	Sand.	Loam.	Clay loam.	Clay.	Resistance at 60° F.	Sand.	Loam.	Clay loam.	Clay.
Ohms.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Ohms.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
24	3.00	....	....	....	130	0.41	0.53	0.59	0.72
25	2.90	3.00	3.00	....	135	.39	.51	.57	.69
30	2.10	2.22	2.22	3.00	140	.38	.49	.55	.66
35	1.64	1.91	1.91	2.55	145	.37	.47	.53	.63
40	1.42	1.72	1.74	2.28	150	.36	.45	.51	.61
45	1.24	1.54	1.56	2.05	155	.35	.44	.50	.59
50	1.30	1.40	1.42	1.87	160	.34	.43	.49	.56
55	1.00	1.27	1.29	1.72	165	.33	.41	.47	.54
60	.87	1.16	1.18	1.60	170	.32	.40	.46	.52
65	.80	1.06	1.08	1.48	175	.31	.39	.45	.51
70	.74	.98	1.00	1.38	180	.31	.38	.44	.49
75	.68	.92	.95	1.29	185	.30	.37	.43	.47
80	.64	.86	.90	1.22	190	.30	.36	.42	.46
85	.59	.81	.86	1.14	195	.29	.35	.41	.45
90	.56	.77	.82	1.08	200	.29	.34	.40	.43
95	.54	.73	.79	1.01	210	.26	.32	.38	.39
100	.51	.69	.75	.97	220	.24	.31	.37	.36
105	.49	.65	.72	.91	240	.21	.28	.34	.33
110	.47	.63	.69	.87	260	.19	.26	.32	.31
115	.45	.60	.66	.83	300	....	.22	.28	.29
120	.43	.57	.64	.79	340	....	.18	.23	.24
125	.42	.55	.61	.75	380	....	....	.20	.20

EFFECT OF ORGANIC MATTER.

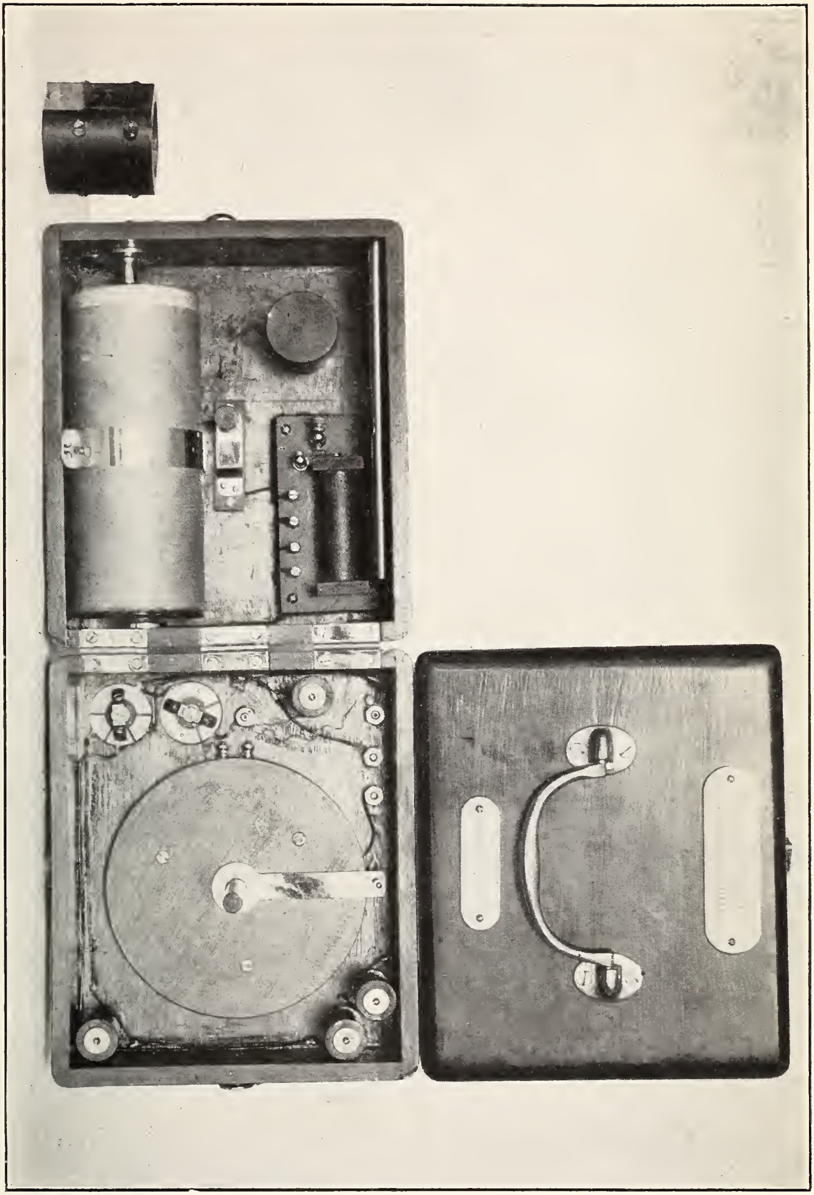
Since it has been suspected that organic matter in the soil has some influence on the conductivity, it was deemed advisable to test this point. Portsmouth sand was selected as a soil containing a large percentage of organic matter, and curves were made for the resistance with the three salts already mentioned. Then curves with the same salts were made with another portion of the soil after burning out the organic matter. The two sets of curves are shown in figures 5, 6, and 7. The sample used contained 4.17 per cent organic matter.

It will be seen from these diagrams that in the cases of sodium chloride and sodium sulphate the curves of the soil with and without the organic matter are practically the same, while in the case of the carbonate there is a marked decrease in the resistance of the latter. In other words, when organic matter is present the bridge method gives lower results for salt content than it should for soils which contain carbonates. The increased conductivity of the soil containing carbonates after its organic matter has been burned out can not be due to an increase in soluble matter produced by ignition, for the curves for sodium chloride ($NaCl$) and sodium sulphate (Na_2SO_4) are the same after ignition as before. If there were a marked change in the amount of soluble material, these curves also would be different.

To secure a better proof of the effect of organic matter, fine quartz was treated with an alkaline solution of humus and the humus then precipitated by the addition of hydrochloric acid. The quartz was then washed thoroughly with water. Most of the organic matter leached out, but the quartz still retained a coating of it, as was shown



Bridge Box with Top Raised, Showing Cup in Position Ready for Use.



BRIDGE BOX OPEN, SHOWING INTERIOR.

by the charring on ignition. The resistance of the quartz before the addition of humus to it, and afterwards, was determined. Before treatment the resistance was 1,252 ohms; after treatment it was

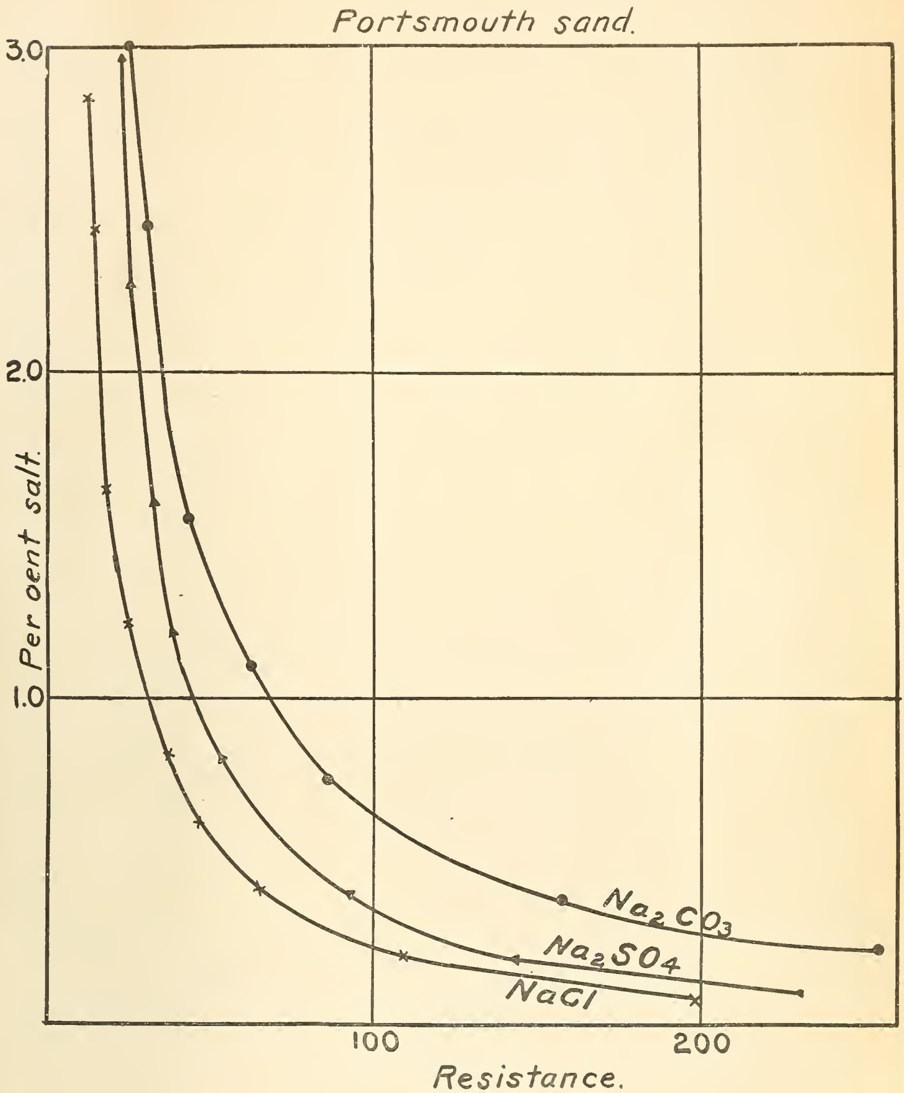


FIG. 5.—Curves for Portsmouth sand with sodium carbonate, sulphate, and chloride.

4,952 ohms. With 0.23 per cent sodium carbonate (Na_2CO_3) added, the pure quartz gave a resistance of 121 ohms and the quartz with humus 127.5 ohms, showing in both cases greater resistance in the presence of organic matter.

TIME REQUIRED FOR EQUILIBRIUM.

If the soil is in perfectly dry condition, on moistening it will require some time for it to come to a state of equilibrium, and the resistance will change during that time. This means, partly, that the soluble salt does not go into solution instantaneously. An additional cause is probably the fact that salts exhibit the phenomena of absorption in varying degrees, depending on the nature of the salt and soil, the

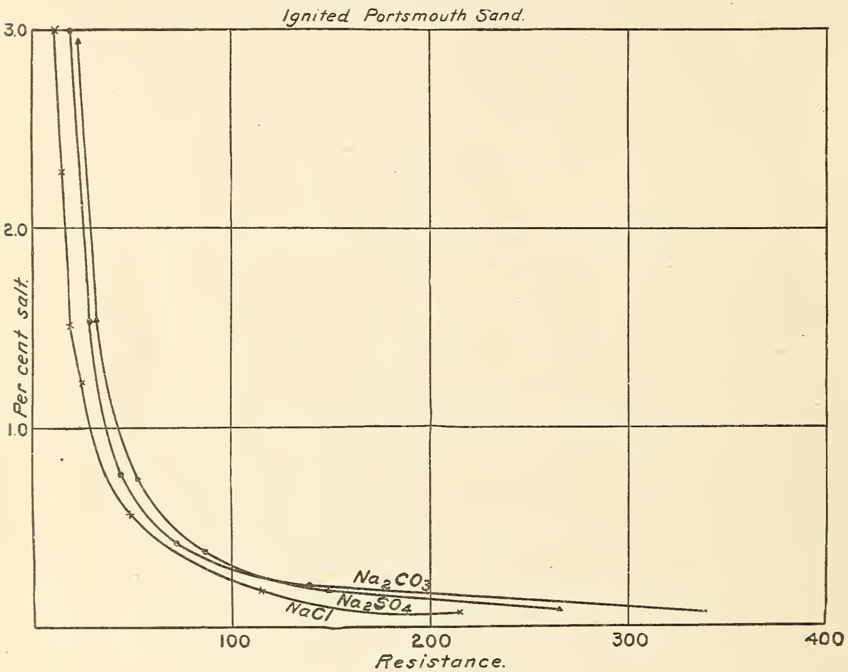


FIG. 6.—Curves for ignited Portsmouth sand with sodium carbonate, sulphate, and chloride.

carbonates showing it in the greatest degree, the sulphates less, and the chlorides least. Some experiments were made to determine the length of time required for this equilibrium to be established by measuring the resistance and noting how long it required to become constant. These results are given in Table VII, from which we see that with sodium carbonate, twenty to twenty-five minutes are required; with sodium sulphate, fifteen minutes; and with chloride, five minutes.

TABLE VII.—*Time required for equilibrium of different salts.*

Salt.	Soil.	Salt content.	Time.	Resistance.
		Per cent.	*Minutes.*	*Ohms.*
Na_2CO_3	Sand	1.55	....	33.2
		1.55	2	32.8
		1.55	7	29.1
		1.55	10	26.6
		1.55	12	26.6
		1.55	17	25.8
		1.55	22	25.1
		1.55	27	25.1
Na_2CO_3	Sand	1.10	....	45.3
		1.10	10	33.2
		1.10	15	30.8
		1.10	20	29.4
		1.10	25	29.4
Na_2SO_4	Sand	1.00	....	75.7
		1.00	5	67.2
		1.00	10	54.0
		1.00	15	51.3
		1.00	20	51.3
		1.00	25	51.2
NaCl	Sand	1.00	....	39.0
		1.00	5	37.9
		1.00	10	37.9

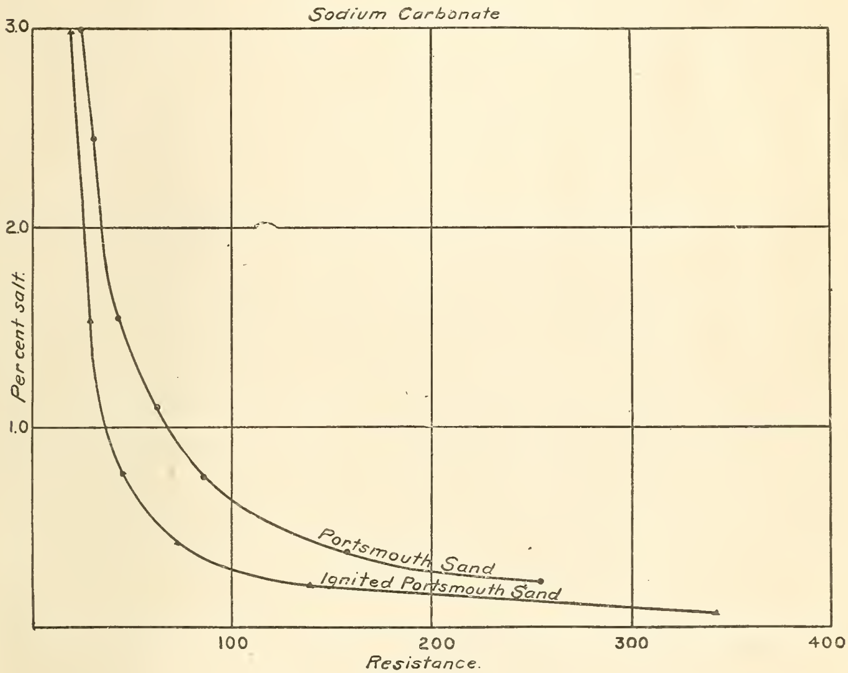


FIG. 7.—Curves for sodium carbonate with Portsmouth sand and ignited Portsmouth sand.

MEASUREMENT OF CONCENTRATED SOLUTIONS.

With concentrated solutions, sometimes a sharp minimum can not be obtained, using the cup full of solution. Experiments were made to determine whether the cup might be partially filled and accurate enough measurements made. Thus the resistance of the

cup one-fifth full divided by five should give the resistance of the cup when full. In Table VIII are given the results of measurements made with different quantities of solution in the cup. It is seen that the results are accurate enough for measurements on concentrated solutions.

The measurements may be made on concentrated solutions, with the cup full, if use is made of the extra 100-ohm coil in the new bridge. By experiment it was determined that by placing an extra resistance in series with the cup, when the resistance of the cup contents was low, the minimum point on the bridge could be located much more easily. By throwing in circuit the extra 100 ohms, differences in resistance down to 1 ohm may be read on the bridge.

TABLE VIII.—*Resistance of partially filled cup.*

SOLUTION CONTAINING OVER 9 PER CENT SALT.

Amount in cup.	Resistance read.	Resistance of 50 c. c. calculated.
Cubic centimeters.	*Ohms.*	*Ohms.*
5	41.0	4.1
10	21.5	4.3
20	10.2	4.1
30	7.0	4.2
50	4.2	4.2

SOLUTION CONTAINING OVER 8 PER CENT SALT.

5	52.0	5.2
10	26.0	5.2
20	12.5	5.0
30	8.2	4.9
50	5.0	5.0

CONCLUSIONS.

From the experimental work with the bridge it is found that—

The resistance of a soil having the same salt content increases with an increase in the fineness of texture of the soil.

Where the salt is partly carbonates the resistance is much greater than when other salts alone are present.

The presence of organic matter increases the resistance for the same salt content.

If a soil is dry, the reading for resistance should not be made until twenty minutes have elapsed after moistening.

Accurate enough results may be obtained with concentrated solutions by reading resistances with the cup partly filled.

On applying these conclusions to the use of the bridge in the field it is apparent that the method reaches its full accuracy only when the alkali contains little or no carbonate and when the organic matter content of the soil is small. Under these conditions the salt con-

tent as determined from the bridge reading by the use of Tables II and III will be very near the truth. In the presence of carbonates it is necessary to construct a special table (as hereinafter described) for the particular combination of carbonates and other salts which is found in the area being examined. By the use of such a table carbonate alkali can be quite well measured as long as the ratios of the various salts to each other do not greatly change. In areas in which the proportion of carbonate in the alkali is widely variable the bridge readings must be regarded as rough indications only and must be closely checked by chemical analysis.

The presence of much organic matter is equally fatal to the usefulness of the method. If the character and amount of the organic matter is uniform throughout the area, a special standard may be prepared, using local soil as well as local alkali.[a] But not only is the preparation of this standard very laborious, but the requisite constancy in the nature and quantity of the organic matter is seldom present. In general, therefore, it is better to abandon the bridge on soils high in organic matter (except for very rough work) and fall back on chemical methods. The limit of organic matter which is permissible can not be very exactly specified. It depends greatly on local conditions. Perhaps 5 per cent (by weight) should be considered dangerous and 10 per cent fatal. These percentages are still lower when much carbonate is present.

THE TEMPERATURE CORRECTION.

In general, the conductance of electrolytes increases with a rise in temperature. Hence it is of importance that measurements of resistance must either be made at the same temperature or reduced to the same temperature

The temperature coefficient of a solution is not the same as that of a soil saturated with the solution. This fact has been noted by Whitney and Briggs,[b] who found that the temperature coefficients of nine types of soil were very close together, but that they were a little greater than the coefficient of pure sodium chloride solution.

A solution of salt in water is homogeneous throughout, and hence a change in temperature changes the temperature coefficient uniformly through the whole solution. The temperature coefficient of a soil saturated with this solution is different. This change in the temperature coefficient is probably due to absorption of dissolved particles. It is a well-known fact that it is very hard to wash out salt in solution from a soil or finely divided powder. The condition of the soil solu-

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[a] Tables II and III do not apply and hence the method given on pages 25 and 26 can not be used. The entire calibration as described on page 29 must be repeated and the data of Tables II and III redetermined for the soils in question.

[b] Bul. No. 7, Division of Soils, U. S. Dept. of Agr., 1897, p. 10.

tion is changed. The dissolved particles may form a somewhat more concentrated layer of liquid upon the surface of the soil grains. This leaves the mass of the interstitial solution of less concentration. There are thus two conducting layers, the conductance of each of which is different from that of the original solution, and each with a different temperature coefficient. Hence the conductance of the wet soil, and therefore the temperature coefficient, is made up of these two factors, resulting in a new temperature coefficient.

From measurements of the temperature coefficients of the nine types of soil by Briggs, Means[a] has worked out a table for correcting to temperature of 60° F. the measurements made at temperatures from 32° to 100° F. His data are reproduced in Table IX.

As an example of its use, suppose the resistance to be 1,349 ohms at 72° F. On the left-hand side of the table find 72°, then opposite under the column marked 1,000 will be found 1,170 ohms at 60° as the value of 1,000 at 72°; 3,000 ohms at 72° will be found equal to 3,510 at 60°, hence 300 is equal to 351 at 60°; 40 is equal to 46.8 ohms at 60°, and 9 is equal to 10.5 ohms at 60°.

Add these values together:

1, 000	1, 170
300	351
40	46. 8
9	10. 5

at 72° F., 1, 349=1, 578. 3 ohms at 60° F.

In a similar manner the table may be used for the reduction of any resistance to 60° F.

TABLE IX.—*Reduction of the electrical resistance of soils to a uniform temperature of 60° F.*

°F.	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
32. 0	625	1, 250	1, 875	2, 500	3, 125	3, 750	4, 375	5, 000	5, 625
32. 5	632	1, 265	1, 897	2, 530	3, 163	3, 795	4, 425	5, 059	5, 691
33. 0	640	1, 280	1, 920	2, 560	3, 200	3. 840	4, 480	5, 120	5, 760
33. 5	647	1, 294	1, 941	2, 588	3, 235	3, 883	4, 530	5, 177	5, 824
34. 0	653	1, 306	1, 959	2, 612	3, 265	3, 918	4, 571	5, 224	5, 877
34. 5	660	1, 320	1, 980	2, 640	3, 300	3, 960	4, 620	5, 280	5, 940
35. 0	668	1, 336	2, 004	2, 672	3, 340	4, 008	4, 676	5, 344	6, 012
35. 5	675	1, 350	2, 025	2, 700	3, 375	4, 050	4, 725	5, 400	6, 075
36. 0	683	1, 366	2, 049	2, 732	3, 415	4, 098	4, 781	5, 464	6, 147
36. 5	690	1, 380	2, 070	2, 760	3, 450	4, 140	4, 830	5, 520	6, 210
37. 0	698	1, 396	2, 094	2, 792	3, 490	4, 188	4, 886	5, 584	6, 282
37. 5	704	1, 408	2, 112	2, 816	3, 520	4, 224	4, 928	5, 632	6, 336
38. 0	711	1, 422	2, 133	2, 844	3, 555	4, 266	4, 977	5, 688	6, 399
38. 5	717	1, 434	2, 151	2, 868	3, 585	4, 302	5, 019	5, 736	6, 453
39. 0	723	1, 446	2, 169	2, 892	3, 615	4, 338	5, 061	5, 784	6, 507
39. 5	729	1, 458	2, 187	2, 916	3, 645	4, 374	5, 103	5, 832	6, 561

[a] Bul. No. 8, Division of Soils, U. S. Dept. of Agr., 1897, p. 28.

TABLE IX.—*Reduction of the electrical resistance of soils to a uniform temperature of 60° F.*—Continued.

° F.	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
40.0	735	1,470	2,205	2,940	3,675	4,410	5,145	5,880	6,615
40.5	742	1,484	2,226	2,968	3,710	4,452	5,194	5,936	6,678
41.0	750	1,500	2,250	3,000	3,750	4,500	5,250	6,000	6,750
41.5	757	1,514	2,271	3,028	3,785	4,542	5,299	6,056	6,813
42.0	763	1,526	2,289	3,052	3,815	4,578	5,341	6,104	6,867
42.5	770	1,540	2,310	3,080	3,850	4,620	5,390	6,160	6,930
43.0	776	1,552	2,328	3,104	3,880	4,656	5,432	6,208	6,984
43.5	782	1,564	2,346	3,128	3,910	4,692	5,474	6,256	7,038
44.0	788	1,576	2,364	3,152	3,940	4,728	5,516	6,304	7,092
44.5	794	1,588	2,382	3,176	3,970	4,764	5,558	6,352	7,146
45.0	800	1,600	2,400	3,200	4,000	4,800	5,600	6,400	7,200
45.5	807	1,614	2,421	3,228	4,035	4,842	5,649	6,456	7,263
46.0	814	1,628	2,442	3,256	4,070	4,884	5,698	6,512	7,326
46.5	821	1,642	2,463	3,284	4,105	4,926	5,747	6,568	7,389
47.0	828	1,656	2,484	3,312	4,140	4,968	5,796	6,624	7,452
47.5	835	1,670	2,505	3,340	4,175	5,010	5,845	6,680	7,515
48.0	843	1,686	2,529	3,372	4,215	5,058	5,901	6,744	7,587
48.5	850	1,700	2,550	3,400	4,250	5,100	5,950	6,800	7,650
49.0	856	1,712	2,568	3,424	4,280	5,136	5,992	6,848	7,704
49.5	862	1,724	2,586	3,448	4,310	5,172	6,034	6,896	7,758
50.0	867	1,734	2,601	3,468	4,335	5,202	6,069	6,936	7,803
50.5	874	1,748	2,622	3,496	4,370	5,244	6,118	6,992	7,866
51.0	881	1,762	2,643	3,524	4,405	5,286	6,167	7,048	7,929
51.5	887	1,774	2,661	3,548	4,435	5,322	6,209	7,096	7,983
52.0	893	1,786	2,679	3,572	4,465	5,358	6,251	7,144	8,037
52.5	900	1,800	2,700	3,600	4,500	5,400	6,300	7,200	8,100
53.0	906	1,812	2,718	3,624	4,530	5,436	6,342	7,248	8,154
53.5	912	1,824	2,736	3,648	4,560	5,472	6,384	7,296	8,208
54.0	917	1,834	2,751	3,668	4,585	5,502	6,419	7,336	8,253
54.5	925	1,850	2,775	3,700	4,625	5,550	6,475	7,400	8,325
55.0	933	1,866	2,799	3,732	4,665	5,598	6,531	7,464	8,397
55.5	940	1,880	2,820	3,760	4,700	5,640	6,580	7,520	8,460
56.0	947	1,894	2,841	3,780	4,735	5,682	6,629	7,576	8,523
56.5	954	1,908	2,862	3,816	4,770	5,724	6,678	7,632	8,586
57.0	961	1,922	2,883	3,844	4,805	5,766	6,727	7,688	8,649
57.5	968	1,936	2,904	3,872	4,839	5,807	6,775	7,743	8,711
58.0	974	1,948	2,922	3,896	4,870	5,844	6,818	7,792	8,766
58.5	981	1,961	2,942	3,923	4,903	5,884	6,864	7,845	8,826
59.0	987	1,974	2,962	3,949	4,936	5,923	6,910	7,898	8,885
59.5	994	1,988	2,982	3,976	4,971	5,965	6,959	7,953	8,947
60.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
60.5	1,006	2,013	3,019	4,026	5,032	6,039	7,045	8,052	9,059
61.0	1,013	2,026	3,039	4,052	5,065	6,078	7,091	8,104	9,117
61.5	1,020	2,040	3,060	4,080	5,100	6,120	7,140	8,160	9,180
62.0	1,027	2,054	3,081	4,108	5,135	6,162	7,189	8,216	9,243
62.5	1,033	2,067	3,100	4,134	5,167	6,201	7,234	8,268	9,302
63.0	1,040	2,080	3,120	4,160	5,200	6,240	7,280	8,320	9,360
63.5	1,047	2,094	3,141	4,188	5,235	6,282	7,329	8,376	9,423
64.0	1,054	2,108	3,162	4,216	5,270	6,324	7,378	8,432	9,486
64.5	1,060	2,121	3,181	4,242	5,302	6,363	7,423	8,484	9,545
65.0	1,067	2,134	3,201	4,268	5,335	6,402	7,469	8,536	9,603
65.5	1,074	2,148	3,222	4,296	5,370	6,444	7,518	8,592	9,666
66.0	1,081	2,162	3,243	4,324	5,405	6,486	7,567	8,648	9,729
66.5	1,088	2,176	3,264	4,352	5,440	6,528	7,616	8,704	9,792
67.0	1,095	2,190	3,285	4,380	5,475	6,570	7,665	8,760	9,855
67.5	1,102	2,205	3,307	4,410	5,512	6,615	7,717	8,820	9,922
68.0	1,110	2,220	3,330	4,440	5,550	6,660	7,770	8,880	9,990
68.5	1,117	2,235	3,352	4,470	5,587	6,705	7,823	8,940	10,058
69.0	1,125	2,250	3,375	4,500	5,625	6,750	7,875	9,000	10,125
69.5	1,133	2,265	3,398	4,530	5,663	6,795	7,928	9,060	10,193

TABLE IX.—*Reduction of the electrical resistance of soils to a uniform temperature of 60° F.*—Continued.

° F.	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
70.0	1,140	2,280	3,420	4,560	5,700	6,840	7,980	9,120	10,260
70.5	1,147	2,285	3,442	4,590	5,737	6,885	8,032	9,180	10,327
71.0	1,155	2,310	3,465	4,620	5,775	6,930	8,085	9,240	10,395
71.5	1,162	2,325	3,487	4,650	5,812	6,975	8,137	9,300	10,462
72.0	1,170	2,340	3,510	4,680	5,850	7,020	8,190	9,360	10,530
72.5	1,177	2,355	3,532	4,710	5,887	7,065	8,242	9,420	10,597
73.0	1,185	2,370	3,555	4,740	5,925	7,110	8,295	9,480	10,665
73.5	1,193	2,386	3,579	4,772	5,965	7,158	8,351	9,544	10,737
74.0	1,201	2,402	3,603	4,804	6,005	7,206	8,407	9,608	10,809
74.5	1,208	2,416	3,624	4,832	6,040	7,248	8,456	9,664	10,872
75.0	1,215	2,430	3,645	4,860	6,075	7,290	8,505	9,720	10,935
75.5	1,222	2,445	3,667	4,890	6,112	7,335	8,557	9,780	11,002
76.0	1,230	2,460	3,690	4,920	6,150	7,380	8,610	9,840	11,070
76.5	1,237	2,475	3,712	4,950	6,187	7,425	8,662	9,900	11,137
77.0	1,245	2,490	3,735	4,980	6,225	7,470	8,715	9,960	11,205
77.5	1,253	2,506	3,759	5,012	6,265	7,518	8,771	10,024	11,277
78.0	1,261	2,522	3,783	5,044	6,305	7,566	8,827	10,088	11,349
78.5	1,269	2,538	3,807	5,076	6,345	7,614	8,883	10,152	11,421
79.0	1,277	2,554	3,831	5,108	6,385	7,662	8,939	10,216	11,493
79.5	1,285	2,576	3,856	5,142	6,427	7,713	8,998	10,284	11,569
80.0	1,294	2,598	3,882	5,176	6,470	7,764	9,058	10,352	11,646
80.5	1,302	2,609	3,906	5,208	6,510	7,812	9,114	10,416	11,718
81.0	1,310	2,620	3,930	5,240	6,550	7,860	9,170	10,480	11,790
81.5	1,318	2,637	3,955	5,274	6,592	7,911	9,229	10,546	11,866
82.0	1,327	2,654	3,981	5,308	6,635	7,962	9,289	10,616	11,943
82.5	1,335	2,670	4,005	5,340	6,675	8,010	9,345	10,680	12,015
83.0	1,343	2,686	4,029	5,372	6,715	8,058	9,401	10,744	12,087
83.5	1,351	2,702	4,053	5,404	6,755	8,106	9,457	10,808	12,159
84.0	1,359	2,718	4,077	5,436	6,795	8,154	9,513	10,872	12,231
84.5	1,367	2,735	4,102	5,470	6,837	8,205	9,572	10,940	12,307
85.0	1,376	2,752	4,128	5,504	6,830	8,256	9,632	11,008	12,384
85.5	1,385	2,769	4,153	5,538	6,922	8,307	9,691	11,076	12,460
86.0	1,393	2,786	4,179	5,572	6,965	8,358	9,751	11,144	12,537
86.5	1,401	2,802	4,203	5,604	7,005	8,406	9,807	11,208	12,609
87.0	1,409	2,818	4,227	5,636	7,045	8,454	9,863	11,272	12,681
87.5	1,418	2,836	4,254	5,672	7,090	8,508	9,931	11,344	12,762
88.0	1,427	2,854	4,281	5,708	7,135	8,562	9,989	11,416	12,843
88.5	1,435	2,870	4,305	5,740	7,175	8,610	10,040	11,480	12,915
89.0	1,443	2,886	4,329	5,772	7,215	8,658	10,091	11,544	12,987
89.5	1,451	2,903	4,354	5,806	7,257	8,709	10,155	11,612	13,063
90.0	1,460	2,920	4,380	5,840	7,300	8,760	10,220	11,680	13,140
90.5	1,468	2,937	4,405	5,874	7,342	8,811	10,279	11,748	13,216
91.0	1,477	2,954	4,431	5,908	7,385	8,862	10,339	11,816	13,293
91.5	1,486	2,972	4,458	5,944	7,430	8,916	10,402	11,888	13,374
92.0	1,495	2,990	4,485	5,980	7,475	8,970	10,465	11,960	13,455
92.5	1,504	3,008	4,512	6,016	7,520	9,024	10,528	12,032	13,536
93.0	1,513	3,026	4,539	6,052	7,565	9,078	10,591	12,104	13,617
93.5	1,522	3,035	4,567	6,090	7,612	9,135	10,657	12,180	13,702
94.0	1,532	3,064	4,596	6,128	7,660	9,192	10,724	12,256	13,788
94.5	1,541	3,083	4,624	6,166	7,707	9,249	10,790	12,332	13,873
95.0	1,551	3,102	4,653	6,204	7,755	9,306	10,857	12,408	13,959
95.5	1,560	3,121	4,681	6,242	7,802	9,363	10,923	12,484	14,040
96.0	1,570	3,140	4,710	6,280	7,850	9,420	10,990	12,560	14,130
96.5	1,580	3,160	4,740	6,320	7,900	9,480	11,060	12,640	14,220
97.0	1,590	3,180	4,770	6,360	7,950	9,540	11,130	12,720	14,310
97.5	1,600	3,201	4,801	6,402	8,002	9,603	11,203	12,804	14,404
98.0	1,611	3,222	4,833	6,444	8,055	9,666	11,277	12,888	14,499
98.5	1,620	3,240	4,860	6,480	8,100	9,720	11,340	12,960	14,580
99.0	1,629	3,258	4,887	6,516	8,145	9,774	11,403	13,032	14,661

FIELD DIRECTIONS FOR THE USE OF THE BRIDGE.

In using the bridge for the determination of soluble salt in a soil, the soil is moistened with distilled water and thoroughly mixed. It is necessary to add water enough to saturate the soil; that is, to fill the interstitial spaces. An easy test for determining when saturation has taken place is to strike the soil with the flat blade of the spatula used in mixing. If little bubbles of air are seen to form and break upon the surface, the soil is saturated. Experiment has shown that this test for saturation enables one to duplicate the water content within about 1 per cent. The maximum difference in the amount of water added to a cup full of a given type of soil in order to saturate it was 1.4 c. c.; the average difference, 0.2 c. c. In operating the bridge, the cup is filled with the wet soil or the soil water. If the soil is very dry, about twenty minutes should elapse after moistening before making a measurement. In filling the cup with soil, care should be exercised to avoid air spaces, and air bubbles should be removed by tapping the cup on the ground several times while filling. The top of the soil is struck off level with the top of the cup. After filling, the cup is placed in the clips provided for it. If the telephone receiver of the instrument is placed against the ear and the plunger pressed down, a buzzing sound will be heard. Still holding the plunger down, the pointer is rotated back and forth until the position is located at which the sound in the telephone disappears or is at a minimum. If a balance is not obtained with 10 ohms resistance in the known arm, then the 100 and the 1,000 ohm coils must be tried. If 10 ohms gives a minimum but with the exact position not determinable, throw the extra 100 ohms in series with the cup by means of the switch, *G*, and establish equilibrium as before. The coil which throws the minimum nearest the middle of the bridge is the best one to use.

The resistance of the cup contents is found by multiplying the resistance of the comparison coil used, shown on the rotary switch, *F*, by the number on the scale opposite the pointer, when a balance is established. Thus, if the comparison coil is 100 and the scale reading 0.92, the resistance of the cup is 92 ohms. When the extra 100-ohm coil is used with the cup, the 100 ohms added must be subtracted from the resistance read on the scale. Thus, if the 100 ohms is in series with the cup and the scale reads 1.2, while the comparison coil shows 100 ohms, then the resistance of the cup and coil is 120 ohms. Subtracting the 100 ohms of the coil leaves 20 ohms as the resistance due to the cup. The resistance of the cup contents must be corrected to a temperature of 60° F. To do this, immediately after reading the resistance, a thermometer is stuck into the cup and read after two minutes. The resistance at the temperature found is then corrected

to 60° according to Table IX. Having found the resistance of the cup contents, the percentage of salt may be determined for soils by use of Tables II and III, and for soil solutions by Table XI.

STANDARDIZING AN AREA.

For survey purposes, and in areas where neither soil nor alkali is abnormal in character, the values obtained from Tables II and III, correcting the bridge reading for the temperature, are sufficiently accurate. If more accurate work is required, or it is thought that the values given do not suit the conditions of a particular area, a special standard for the area may be made as follows:

Eight or ten salt crusts or strong alkali soils of the area should be collected and mixed together. Of this mixture take several hundred grams and add about twice its volume of water. Stir thoroughly and filter off the solution. Evaporate 100 c. c. of this solution in a weighed vessel to dryness. Gently ignite to remove water of crystallization and organic matter. Allow the vessel to cool, and reweigh. The gain in weight of the vessel in grams is equal to the percentage of salt in the solution. Preserve the residue in the dish to test for carbonates or test the original solution. If the solution is stronger than 3 per cent, it should be diluted until it is of that strength; if it is weaker, it should be concentrated by evaporation until it is approximately 3 per cent. If necessary to concentrate, then determine after concentration exactly how much salt is in 100 c. c. by evaporation in a weighed vessel, as before; and make the necessary dilution of the main solution in order to obtain a 3 per cent salt content. Having obtained a 3 per cent solution, measure its resistance. Then by systematic dilution make 1.00, 0.60, 0.40, and 0.20 per cent solutions, and measure the resistance of each, reducing the values to 60° F. The dilutions may be made as follows: 33.3 c. c. of 3 per cent diluted to 100 c. c. gives 1 per cent solution; 60 c. c. of 1 per cent solution diluted to 100 c. c. gives 0.60 per cent solution; 66.7 c. c. of 0.60 per cent solution diluted to 100 c. c. gives 0.40 per cent solution; and 50 c. c. of 0.40 per cent solution diluted to 100 c. c. gives 0.20 per cent solution. Now test the residue from evaporation for carbonates by the addition of hydrochloric acid. Carbonates will cause an effervescence. If there is little or no carbonate present, Table II may be used, and the resistances of the solution at the various percentages multiplied by the ratios in the table for the soils give the resistances of the saturated soil with the same percentage salt content in the dry soil. From these values the new curve is constructed.

If the test for carbonates shows that there is much of those salts present, the measured resistances for the solution should be multiplied by the ratios given in Table X, which are ratios derived from those given in Tables II and V at the given percentages, assuming one-third

the salt present to be carbonate. For exceptional accuracy, the percentages of carbonates in the salt may be determined and a corresponding new ratio, proportional to the amount of carbonate present, obtained.

TABLE X.—*Ratios of resistances of soils containing carbonates to resistances of solution containing carbonates.*

Per cent.	Sand.	Loam.	Clay loam.	Clay.
3.00	1.53	1.69	1.76	1.98
1.00	1.70	1.95	2.02	2.48
.60	1.75	2.09	2.26	2.70
.40	1.83	2.10	2.40	2.56
.20	1.89	2.11	2.40	2.48

USE ON SOIL SOLUTIONS.

For using the bridge with soil solutions, the cup is filled with the solution and the reading of resistance made just as with soils. After correcting for temperature, the parts per 1,000,000 of salt in solution are determined by use of Table XI, which is here reproduced for convenience from a publication by King and Whitson.[a] The table has been verified by checking at a number of points. This method of determining the soluble salt in a soil solution has been in use in the laboratory for some time, and where great accuracy is not required it results in an important saving of time.

TABLE XI.—*Soluble salts in soil solutions at 60° F.*

R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.
68	3,500	88	542	108	59	128	1700	148	450	168	268	188	1,121
69	400	89	513	109	39	129	685	149	440	169	260	189	1,114
70	300	90	484	110	19	130	670	150	430	170	252	190	107
71	250	91	456	111	2,000	131	655	151	420	171	244	191	100
72	200	92	427	112	1,981	132	640	152	410	172	236	192	93
73	150	93	400	113	962	133	626	153	400	173	228	193	86
74	100	94	375	114	943	134	613	154	390	174	220	194	80
75	50	95	350	115	924	135	600	155	380	175	212	195	74
76	3,000	96	325	116	905	136	587	156	370	176	205	196	68
77	2,950	97	300	117	887	137	574	157	360	177	198	197	62
78	900	98	276	118	869	138	562	158	350	178	191	198	56
79	850	99	253	119	851	139	550	159	341	179	184	199	50
80	800	100	230	120	834	140	538	160	332	180	177	200	44
81	767	101	208	121	817	141	527	161	324	181	170	201	38
82	733	102	186	122	800	142	516	162	316	182	163	202	32
83	700	103	164	123	783	143	505	163	308	183	156	203	26
84	667	104	142	124	766	144	494	164	300	184	149	204	20
85	633	105	121	125	749	145	483	165	292	185	142	205	14
86	600	106	100	126	732	146	472	166	284	186	135	206	8
87	571	107	79	127	715	147	461	167	276	187	128	207	2

[a] Bul. No. 85, Wisconsin Agr. Expt. Sta., 1901.

TABLE XI.—*Soluble salts in soil solutions at 60° F.*—Continued.

R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.
208	996	274	716	338	580	383.5	514	433.8	449	502	384	598	319
209	990	274	713	339	578	384	513	434.6	448	503	383	600	318
210	985	275	710	340	577	384.5	512	435.4	447	504	382	601.5	317
211	980	276	707	341	576	385	511	436.2	446	505.5	381	603	316
212	975	277	704	342	575	386	510	437	445	507	380	605	315
213	970	278	701	343	574	386.5	509	438.0	444	508	379	607	314
214	965	279	698	344	573	387	508	439.0	443	509	378	609	313
215	960	280	696	345	572	387.5	507	440.0	442	510.5	377	611	312
216	955	281	694	346	571	388	506	441.0	441	512	376	612.5	311
217	950	282	692	347	570	389	505	442	440	513	375	614	310
218	945	283	690	348	569	390	504	442.8	439	514	374	616	309
219	940	284	688	349	568	390.5	503	443.6	438	515.5	373	618	308
220	935	285	686	350	567	391	502	444.4	437	517	372	620	307
221	930	286	684	351	566	391.5	501	445.2	436	518.5	371	622	306
222	925	287	682	352	565	392	500	446	435	520	370	624	305
223	920	288	680	353	564	392.5	499	447	434	521	369	626	304
224	915	289	678	354	563	393	498	448	433	522	368	628	303
225	910	290	676	355	562	393.5	497	449	432	523.5	367	630	302
226	905	291	674	356	561	394	496	450	431	525	366	632	301
227	900	292	672	357	560	394.5	495	451	430	526	365	634	300
228	895	293	670	358	559	395	494	452	429	527	364	636	299
229	890	294	668	359	558	396	493	453	428	528.5	363	638	298
230	885	295	666	360	557	397	492	454	427	530	362	640	297
231	880	296	664	361	556	398	491	455	426	531.5	361	642	296
232	875	297	662	362	555	399	490	456	425	533	360	644	295
233	870	298	660	263	554	400	489	457	424	534.5	359	646	294
234	865	299	658	364	553	400.8	488	458	423	536	358	648	293
235	860	300	656	364.5	552	401.6	487	459	422	537.5	357	650	292
236	855	301	654	365	551	402.4	486	460	421	539	356	652	291
237	850	302	652	365.5	550	403	485	461	420	540.5	355	654	290
238	845	303	650	366	549	403.8	484	462	419	542	354	656	289
239	840	304	648	366.5	548	404.6	483	463	418	543.5	353	658	288
240	835	305	646	367	547	405.4	482	464	417	545	352	661.5	287
241	830	306	644	367.5	546	406.2	481	465	416	546.5	351	663	286
242	825	307	642	368	545	407	480	466	415	548	350	665	285
243	820	308	640	368.5	544	407.8	479	467	414	549.5	349	667	284
244	815	309	638	369	543	408.6	478	468	413	551	348	669.5	283
245	810	310	636	369.5	542	409.4	477	469	412	552.5	347	672	282
246	805	311	634	370	541	410.2	476	470	411	554	346	674	281
247	800	312	632	370.5	540	411	475	471	410	555.5	345	676	280
248	796	313	630	371	539	411.8	474	472.2	409	557	344	678.5	279
249	792	314	628	371.5	538	412.6	473	473.4	408	558.5	343	681	278
250	788	315	626	372	537	413.4	472	474.6	407	560	342	683	277
251	784	316	624	372.5	536	414.2	471	475.8	406	561.5	341	685	276
252	780	317	622	373	535	415	470	477	405	563	340	687.5	275
253	776	318	620	373.5	534	415.8	469	478	404	565	339	690	274
254	773	319	618	374	533	416.6	468	479	403	567	338	692.5	273
255	770	320	616	374.5	532	417.4	467	480	402	568.5	337	695	272
256	767	321	614	375	531	418.2	466	481	401	570	336	697.5	271
257	764	322	612	375.5	530	419	465	482	400	571.5	335	700	270
258	761	323	610	376	529	420	464	483.2	399	573	334	702	269
259	758	324	608	376.5	528	421.0	463	484.4	398	574.5	333	704	268
260	755	325	606	377	527	422.0	462	485.6	397	576	332	707	267
261	752	326	604	377.5	526	423.0	461	486.8	396	578	331	709	266
262	749	327	602	378	525	424	460	488	395	580	330	712	265
263	746	328	600	378.5	524	424.8	459	489.2	394	581.5	329	715	264
264	743	329	598	379	523	425.6	458	490.4	393	583	328	717	263
265	740	330	596	379.5	522	426.4	457	491.6	392	584.5	327	720	262
266	737	331	594	380	521	427.2	456	492.8	391	586	326	722	261
267	734	332	592	380.5	520	428.0	455	494	390	587.5	325	725	260
268	731	333	590	381	519	429.0	454	495	389	589	324	727	259
269	728	334	588	381.5	518	430.0	453	496	388	591	323	730	258
270	725	335	586	382	517	431.0	452	497.5	387	593	322	732	257
271	722	336	584	382.5	516	432.0	451	499	386	594.5	321	735	256
272	719	337	582	383	515	433	450	500.5	385	596	320	738	255

Table XI.—*Soluble salts in soil solutions at 60° F.*—Continued.

R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.	R. at 60° F.	Parts per million.
740	254	848	219	990	184	1,216	149	1,559	114	2,203	79	3,788	44
743	253	851	218	995	183	1,224	148	1,572	113	2,232	78	3,858	43
746	252	854	217	1,000	182	1,232	147	1,585	112	2,259	77	3,935	42
749	251	858	216	1,005	181	1,240	146	1,599	111	2,288	76	4,005	41
751	250	862	215	1,010	180	1,248	145	1,614	110	2,320	75	4,090	40
754	249	865	214	1,016	179	1,257	144	1,629	109	2,351	74	4,180	39
757	248	869	213	1,022	178	1,265	143	1,645	108	2,383	73	4,275	38
760	247	872	212	1,027	177	1,274	142	1,661	107	2,416	72	4,375	37
762	246	876	211	1,032	176	1,283	141	1,678	106	2,451	71	4,475	36
765	245	880	210	1,038	175	1,292	140	1,695	105	2,486	70	4,580	35
768	244	884	209	1,044	174	1,301	139	1,712	104	2,522	69	4,695	34
771	243	887	208	1,049	173	1,310	138	1,729	103	2,555	68	4,810	33
774	242	891	207	1,055	172	1,320	137	1,746	102	2,593	67	4,925	32
777	241	895	206	1,060	171	1,328	136	1,763	101	2,631	66	5,050	31
780	240	899	205	1,067	170	1,337	135	1,780	100	2,670	65	5,195	30
783	239	903	204	1,073	169	1,346	134	1,797	99	2,712	64	5,340	29
786	238	907	203	1,079	168	1,355	133	1,814	98	2,755	63	5,500	28
789	237	911	202	1,085	167	1,365	132	1,831	97	2,798	62	5,660	27
792	236	915	201	1,091	166	1,374	131	1,848	96	2,842	61	5,820	26
795	235	920	200	1,097	165	1,384	130	1,865	95	2,886	60	6,020	25
798	234	924	199	1,104	164	1,394	129	1,882	94	2,932	59	6,260	24
801	233	928	198	1,110	163	1,404	128	1,900	93	2,978	58	6,560	23
804	232	932	197	1,118	162	1,414	127	1,918	92	3,025	57	6,980	22
807	231	936	196	1,125	161	1,423	126	1,936	91	3,071	56	7,240	21
811	230	940	195	1,132	160	1,433	125	1,954	90	3,120	55	7,600	20
814	229	944	194	1,140	159	1,443	124	1,972	89	3,170	54	7,900	19
817	228	948	193	1,147	158	1,453	123	1,991	88	3,220	53	8,250	18
820	227	953	192	1,154	157	1,464	122	2,011	87	3,277	52	8,800	17
824	226	958	191	1,161	156	1,475	121	2,033	86	3,336	51	9,300	16
827	225	962	190	1,168	155	1,486	120	2,055	85	3,394	50	9,700	15.5
830	224	966	189	1,176	154	1,498	119	2,079	84	3,450	49	10,087	15
834	223	971	188	1,184	153	1,509	118	2,103	83	3,508	48	10,200	14.9
837	222	976	187	1,192	152	1,520	117	2,128	82	3,576	47		
841	221	981	186	1,200	151	1,533	116	2,152	81	3,648	46		
844	220	985	185	1,208	150	1,546	115	2,177	80	3,717	45		

If for any reason, such as the presence of much organic matter in the soil, it is suspected that this table does not give proper values, then it will be necessary to make a new curve. This may be done by obtaining several crusts or samples of the strong alkali soils of the area and preparing a solution as in the standardizing of a soil area. Filter off about 2 quarts and evaporate the solution to a small bulk. Fill the cup with solution and read the resistance on the bridge. After weighing a dish to centigrams, carefully evaporate 100 c. c. of the solution in it; ignite gently to burn off the organic matter and to free the salts of water of crystallization. Allow the dish to cool, then weigh. The gain in weight gives the amount of salt in 100 c. c. of the solution. Every centigram increase in weight means 100 parts of soluble salts in 1,000,000, or 0.01 per cent in the solution. Now, by successive dilutions, a table or curve may be obtained. One may use, for example, 9 parts of solution and 1 part of water; then 8 and 2 of water, etc. This may be done by taking 90 c. c. and adding 10 c. c. of water, then 10 c. c. more, etc. After each dilution the resistance is obtained, and by plotting a curve with resistance and

parts per million as the coordinates any intermediate points may be interpolated. If there are 100 parts in 1,000,000 before dilution, the first dilution of 9 to 1 of water results in a solution with 90 parts per 1,000,000, and so on. With concentrated solutions it is difficult to obtain a minimum on the bridge by use of the comparison coils alone. In such case the cup coil may be thrown in and a minimum may be obtained as described. Or the cup may be only partially filled with the solution. The cup will hold 50 c. c. If 10 c. c. are used, the cup will be one-fifth full and the resistance will be five times as great as the resistance of the cup when filled.

CARE OF THE BRIDGE.

The bridge is a delicate instrument and care should be exercised that it is not damaged by persons unfamiliar with its construction and use. It should not be subjected to any knocks and jars that can be avoided. By rough handling the connections are liable to be broken, the balancing mechanism injured, or parts jostled out of place. The accumulation of dust on its parts may be injurious, hence the box should not be left open when not in use. The bridge wire should be occasionally wiped off with a soft cloth to remove dust that may have collected on it. All the contacts should be occasionally cleaned. Dust on the interrupter of the induction coil may cause trouble. It may be cleaned with a fine brush or soft cloth. Should any of the soldered connections of the bridge be broken, the bridge should be sent to an electrician for repair.

TESTING THE BRIDGE.

The introduction of the 100-ohm coil (cup coil) in the arm of the bridge with the cup is useful not only in making measurements on concentrated solutions, but also to test the correctness of the bridge. In place of the cup a heavy metal piece supplied for the purpose connects the cup clips. On throwing in the extra 100-ohm coil it is the only resistance in that arm of the bridge and should be balanced by 100 ohms in the known arm. If the bridge is in working order, but if the 100 ohms in the cup arm is not balanced by 100 ohms in the comparison coil arm, then correction must be made for the difference. Should the difference be very great, the bridge is probably out of order and should be repaired by a competent electrician.

LOCATION OF FAULTS.

The bridge is so designed that it may have the least possible likelihood to damage, but occasionally it may fail to work. Some probable causes for this are as follows:

On pressing down the plunger no sound may be heard in the telephone receiver, for any of the following reasons: (1) An exhausted

battery; (2) lack of contact of the points in the battery switch, due to dirt thereon; (3) improper adjustment of the current interrupter; (4) broken connections; (5) failure of the contact spring of the balancing mechanism to make contact with the bridge wire; (6) trouble with the telephone.

If, on closing the battery switch, the interrupter gives a buzzing note, but no sound is received in the telephone, the trouble can not be in the battery or interrupter. If the interrupter does not work, see that the switch contacts are clean; then examine the interrupter. By adjusting the screw of the interrupter it can be made to work if the battery is all right. If it does not work, examine the connections of the battery and induction coil. If these are good, then the battery must be replaced by a new one. Should the interrupter work satisfactorily, but no sound be heard in the telephone receiver, a broken circuit exists or the telephone may be out of order. The broken circuit can be found usually by carefully examining the connections. If the difficulty appears to be in the bridge wire, the bridge-wire slide should be examined and adjusted, if necessary, by carefully turning the set screw. When a note is heard in the receiver for a part of the scale only, the trouble is with the bridge-wire contact. In case the fault seems to be in the receiver the connections inside the bridge box should be examined, and then the screws binding the cord terminals. If these are satisfactory, the receiver should be tested directly on the battery circuit.

If the fault is not located by any of the above means, the trouble must be inside the coils. Under such circumstances it is unwise to attempt to remove the trouble by such means as are at hand in the field, and the bridge should be sent to a professional instrument maker or electrician for repair.

DETAILED DESCRIPTION OF THE BRIDGE.

BRIDGE BOX.

The bridge box is made of walnut or cherry wood; closed it is $8\frac{1}{4}$ inches long, 7 inches wide, and 7 inches high. The box is made up of three compartments, the outside measurements of which are: Bottom compartment, $8\frac{1}{4}$ inches long, 7 inches wide, $2\frac{7}{8}$ inches high; middle compartment, $8\frac{1}{4}$ inches long, 7 inches wide, $1\frac{3}{4}$ inches high; top compartment, $8\frac{1}{4}$ inches long, 7 inches wide, $2\frac{3}{8}$ inches high. The material used is $\frac{3}{8}$ inch thick. The top of the middle compartment is raised $\frac{1}{8}$ inch at a distance of $\frac{3}{8}$ inch from the edge all around. The detailed measurements for the construction of the bridge are given in the accompanying drawings. On sheet 1 are the drawings of the assembled instrument, and on sheets 2 and 3 the drawings of the detailed parts. All the brass parts are heavily nickel plated.

BOTTOM COMPARTMENT.

Induction coil.—In order to prevent polarization at the cup electrodes, an alternating current is used. This is obtained from a small induction coil, *C*, supplied with a current interrupter, *D*. The interrupter is made of a strip of phosphor-bronze attached to one binding post. It carries a small piece of soft iron at its loose end, and at its back is soldered a strip of phosphor-bronze bent back upon itself and carrying a platinum plate, which makes contact with a platinum point on the set screw in the other binding post. The coil is mounted on a fiber base and this in turn screwed to the bottom of the box. The base rests upon felt to deaden the sound of the interrupter. The terminals of the secondary coil are soldered to the hinges of the top, which in turn are soldered to wires connecting with the two ends of the bridge wire. The hinges thus form flexible contacts. The primary terminals are connected to the battery, one direct and the other through the battery switch. For the induction coil, *I*, the following construction was found to serve best: Core, $\frac{1}{4}$ inch diameter, of No. 22 B. & S. gauge, soft iron wire; length, $2\frac{3}{4}$ inches; the primary coil, made of four layers, No. 26 magnet wire; the secondary coil, made of seven layers, No. 36 magnet wire. The base is fiber, 4 inches long, 2 inches wide, and is set upon felt $\frac{1}{2}$ inch thick. The interrupter is an ordinary spring interrupter. The binding posts are set in the base and connection made under the base. The outside terminals are secondary and the inside primary. Fiber is used for the base, as it was found to have a smaller coefficient of temperature expansion than hard rubber, and is not so easily broken.

Battery switch.—The switch, *B*, consists of a nickeled brass spring mounted upon a strip of hard rubber, and carrying at its free end a hard rubber button upon which the plunger works when depressed. Contact is made by two brass caps. The switch serves the purpose of closing the circuit for a few minutes only during which a measurement is being made. Thus the battery is in use only when necessary and its life is not unnecessarily shortened. The base of the battery switch, *B*, is $2\frac{1}{4}$ inches long, $\frac{5}{8}$ inch wide, and $\frac{1}{4}$ inch thick. This is fastened to the bottom of the box by two small screws. The spring is $\frac{1}{2}$ inch wide, $1\frac{13}{16}$ inches long. One contact is made with the base, the other with the spring.

Battery.—The battery, *A*, is of flash-light variety, made up of 2 cells placed end to end, giving about 3 volts; it is about 6 inches long and $2\frac{1}{2}$ inches in diameter. It is held on its side and contact is made with its ends; at one end by a fixed brass ring, *S*, against which the end of the battery is pressed, and at the other by a large-headed screw. The flat surface of the screw head makes the contact, and the body of the screw works in a piece attached to the box. Contact is made

through the pieces fastened to the box at each end. The battery is held in place by a brass band, R, $\frac{3}{4}$ inch wide, one end of which is firmly attached to the bottom of the box, and the other end made easily detachable.

Cup post.—The post, Q, over which the inverted cup fits, is hard rubber, $1\frac{1}{2}$ inches long, $1\frac{7}{16}$ inches in diameter; it is fastened to the bottom of the box by a screw entering from below. This forms a convenient place for keeping the cup when not in use.

MIDDLE COMPARTMENT.

Bridge-wire disk.—The disk, E, is made of well-seasoned cherry wood. Before turning out, it is boiled in paraffin until it sinks. It is left in the bath until cool enough for the paraffin to begin solidifying. On removing, the disk will be covered with a layer of solid paraffin. This is scraped off and leaves a thin coating. Wood is used in preference to hard rubber because of its smaller coefficient of expansion. The disk is three-eighths inch thick, $5\frac{1}{8}$ inches in diameter; it has a three-fourths inch hole in the center for the bushing and plunger of the balancing mechanism. It is fastened to the underside of the middle compartment by three five-eighths inch No. 5 flat-head wood screws. The disk has a slight groove in its edge about half as deep as the diameter of the bridge wire.

Bridge wire.—The bridge wire is mounted on the rim of a wooden disk in such a manner that contact may be made with a movable slide. The free ends are fastened to the left and right hand binding posts. The wire is No. 26 platinoid, $21\frac{5}{8}$ inches long. It is drawn taut in the groove on the edge of the disk and is fastened at the ends by posts set one-half inch apart radially in the disk. The short end of the wire is $1\frac{9}{16}$ inches beyond the binding post. The resistance of the entire wire is about 1 ohm. Tests were made with No. 28 manganin wire of the same length, with No. 28, $3\frac{1}{2}$ inches longer, and with low thermoelectric resistance wire No. 26, and none possessed any advantage over the wire used. Platinoid is used because it is harder than the other wires, and hence wears less than the others. It resists oxidation better than manganin wire.

Balancing mechanism.—The rotation of a shaft through a bushing in the cover and the disk, coaxial with the latter, effects a balance in the bridge. The bushing is held in place by a nickeled brass collar, which forms its upper end and is fastened to the cover. From the shaft, just immediately under the lower surface of the disk, extends an arm of brass, parallel to the face of the disk. Just beyond the periphery of the disk the arm carries a contact spring, which is made of spring brass doubled back upon itself, and attached to the arm by a set screw, so that it may be tightened if occasion demands.

The shaft is held in position by means of a collar which carries a set screw, and to which the pointer is attached. The collar thus serves for adjusting the shaft and pointer. Through the center of the shaft there operates a plunger, *O*, for closing the battery circuit. The plunger is of square cross section, as is also a portion of the interior of the shaft, thus allowing free movement along the line of its axis, but preventing rotation within the shaft. To the upper end of the plunger is attached a hard-rubber circular cap, which serves both to operate the plunger and to rotate the balancing mechanism. The lower end of the plunger is cut down for a short distance to a smaller diameter, which works through a corresponding hole in the lower end of the shaft. A weak coiled spring, of just sufficient strength to raise the plunger when released, is placed between the shoulder of the plunger and the bottom of the shaft. To the lower end of the plunger a cylinder of hard rubber is attached. This retains the plunger in place, and on pressing the plunger closes the battery switch.

The detailed construction of the balancing mechanism is shown in the drawing. The contact arm is brass, $3\frac{7}{16}$ inches long, one-half inch wide; at one end is attached the cylinder shaft, $1\frac{1}{8}$ inches long, one-half inch in diameter, which fits into the bushing and is held by a set screw in the indicator; at the other end is the contact spring, of phosphor-bronze with platinum point for contact. The plunger, *O*, of the balancing mechanism is brass, $2\frac{13}{32}$ inches long; one-half inch at the top is a threaded portion one-fourth inch in diameter; below the threaded portion is a cylindrical part, which fits the bushing, three-eighths inch in diameter; and the bottom portion is three-sixteenths inch square cross section, with one-half inch of threaded portion. The hard-rubber cylinder on the end of the plunger is $2\frac{15}{32}$ inches long, three-eighths inch in diameter.

Rotary switches.—The third arm of the bridge is made up of three resistances, which may be thrown together in series. The coils being of 10, 90, and 900 ohms, respectively, and connected to the segments of the rotary switch, *F*, in such manner that 10, 100, or 1,000 ohms can be introduced by using either the 10-ohm coil alone, the 10 and 90, or all three in series. The segments of the rotary switch are mounted on fiber and the spring through which contact is made with the several segments is insulated from the shaft by which it is operated. Contact is made through copper brushes fastended to the shaft. The shaft operating the switch carries on the collar, just below the handle, an index pointer. On the bushing just beneath the pointer are marked the resistances, 10, 100, and 1,000 ohms. These resistances can be thrown into the third arm of the bridge by rotating the switch until the index points to the number desired. The head of the shaft is hard rubber. The rotary switch, *F*, for the coils, is made of four segments set on fiber, $1\frac{1}{4}$ inches in diameter, one-eighth inch thick. The

fiber base is inset in the box three-sixteenths inch. Contact is made by 6 copper bushes on each side, attached to a piece of brass, which in turn is screwed to the shaft. The cup resistance switch, *G*, has the same construction except it is made in two segments instead of four. The connections of the switches are shown in the diagram.

The coils.—The resistance coils, *H*, are attached to the underside of the top by means of long screws. They are wound upon spools of seasoned cherry wood, boiled in paraffin. The spools are $1\frac{1}{4}$ inches long between the cheeks, diameter of core is five-sixteenths inch, diameter of cheeks three-fourths inch, and hole through the center is one-fourth inch. The spools are held in place by brass posts one-fourth inch in diameter, inserted one-fourth inch in the box. The coil is held in place by a washer and screw on top of the posts. There was used for 10-ohm coil: No. 28, B. & S. gauge manganin wire with resistance about 1.7 ohms per foot; for 90 and 100 ohm coils, No. 32 B. & S. gauge manganin wire with resistance of about 3.93 ohms per foot; for 900-ohm coil, No. 36 B. & S. gauge manganin wire with resistance of about 10.3 ohms per foot. After winding, the coils are baked for six hours at 120° C., dipped in melted paraffin, and allowed to age six months before using.

The scale.—The instrument is provided with a scale, *P*, on top of the box, reading direct in terms of resistance of the material in the cup, when multiplied by the resistance of the comparison coil used. It is graduated by cutting out the induction coil and using known metallic resistances and a galvanometer instead of the cup and telephone. The gradations are from 0.3 to 10, so that resistances from 3 to 10,000 ohms may be measured by using the appropriate resistance coil; or, by using a known resistance in series with the cup, resistances down to 1 ohm may be read. The scale is marked upon a brass ring, $5\frac{3}{4}$ inches outside diameter, $4\frac{5}{8}$ inches inside diameter, one-sixteenth inch thick, fastened to the top by five small screws.

Contact clips.—The clips, *K*, for holding the cup are brass pieces 1 inch high and $1\frac{15}{16}$ inches apart. They are held by binding posts which are made so that wires may be fastened to them and metallic resistance introduced in place of the clips. A hard-rubber base is placed between the clips. It is one-eighth inch thick, with two raised points, so that water will not wet across between the clips when the cup is in position. Four small screws fasten it to the box.

Indicator.—The indicator, *N*, which attaches to the top of the shaft carried by the bridge wire contact arm, is made of a square brass piece. It is locked on the top of the shaft by tightening the small screw, which closes the saw slot. The pointer is screwed into the corner of the square brass piece.

Telephone receiver.—The telephone receiver is of the pony form. The terminals are attached to posts, *M*, on the top of the box. One

terminal is connected to the balancing mechanism by means of a spring brass friction contact between the shaft and outer bushing of the balancing mechanism. The other terminal joins the binding post, which is connected with the comparison coils.

Cup.—The cup, I, used in determining the salt content is cylindrical and has a capacity of about 50 c. c. It is made of hard rubber with brass electrodes, heavily nickeled, but not burnished inside, in order to give greater surface and afford better contact with the moist soil. It is turned with $1\frac{1}{2}$ inches inside diameter, $2\frac{3}{32}$ inches outside diameter, and 1.7 inches inside depth. Slots 1 inch wide are cut through and brass electrodes are set in and fastened with 5 screws to each electrode. After finishing, the cup is dipped into warm paraffin to fill the crevices.

Connection is made with the instrument by slipping the cup between two upright brass springs, *K*, which press against the outside of the electrodes and which are connected as one arm of the bridge. Thus, the mercury contacts formerly employed for making connections with the cup are not needed, and the inconvenience occasioned by loss of the mercury in the field is avoided. A plate of hard rubber is fastened to the top of the box between the two clips, so that the cup, when in position, rests upon it and is effectually insulated from the rest of the instrument.

Brass clip.—The brass clip, *L*, is furnished to use in place of the cup in testing the instrument.

TOP.

On the top outside are placed name and number plates and a handle. The catches used for keeping the instrument closed are of the lock-catch variety and are shown in the drawing.

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